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ANCHOR QEA

August 21, 2019

Eric Winiecki
Environmental Protection Agency
1200 Sixth Avenue, Suite 900
Seattle, WA 98101-3140

Re: DOCKET SDWA-10-2013-0080 - Yakima Valley Dairies
Response to July 10 Comment Letter (EPA Letter 202) Regarding the 2018 Annual Report

Dear Eric:

This letter is provided on behalf of the Yakima Valley Dairies, including 1) Cow Palace Dairy, LLC, 2) D & A Dairy, LLC (also known as D&A Dairy LLC), George DeRuyter & Son Dairy, LLC, and George & Margaret, LLC; and 3) Liberty Dairy LLC and its associated dairy facility H&S Bosma Dairy. It accompanies and supplements our revisions to the Draft 2018 Annual Report (Report).

1. Scope of the Updated Report

In developing our revisions to the Report, it is our intent to be responsive to your comments and provide additional information in good faith, where possible. In doing so we have included some edits and additional information that was requested, but that appears to be beyond the scope of the annual report. The defined purpose of the annual report is to "...(a) describe the activities undertaken pursuant to Administrative Order on Consent this Consent Order over the prior year; and (b) present cumulative data in tabulated forms:

> *No later than March 1 of each year after the Effective Date, beginning in 2014, Respondents shall provide to the EPA an Annual Report which shall describe all activities undertaken pursuant to this Consent Order over the prior year. All data shall be presented with cumulative results reflecting prior years and shall be summarized and presented in tabulated form. Data shall be organized by Dairy Facility and type of data. For example, soil data shall be organized by Dairy Facility and application field at that Dairy Facility, etc. The Annual Report shall include, at a minimum, a table and a chart for each application field that displays the measured nitrogen soil levels for the current year and all previous years for which data is available, so that a trend, if any, may be observed at each sampling depth. The Annual Report shall include the Groundwater Monitoring Data Report for each year which shall contain the complete set of data collected from the monitoring wells to date and a chart showing nitrate*

> *concentrations in each well over time. Respondents may cease submitting these Annual Reports to the EPA upon termination of the Consent Order.* (SOW Section III.K.2.).

EPA's letters have repeatedly referenced AOC Section 14 as a foundation for virtually any revisions it requests to our reports, including the 2018 Annual Report. But we note that any such revisions must still be "consistent with the Statement of Work" (AOC Section 14.b.). Several comments appear oddly out of context for a letter purporting to comment on the contents of an annual report. Nonetheless, we have included some information beyond the scope of the annual report in this revised draft but clarify the Dairies are not consenting to an expansion of the SOW or the purpose of that report.

2. Observations of Progress and the Costs of AOC Implementation

In the first of your general comments, you describe some of the progress that has been made at the Dairies. Indeed, the Dairies have invested a great deal of time and money to comply in good faith with their commitments under the AOC and implement associated source control and monitoring actions. As you noted there have been many accomplishments: nutrient concentrations in the fields have been reduced, improvements have been made to manure handling, separation, treatment and storage systems, and improvements have been noted in the quality of groundwater in a significant number of the groundwater monitoring wells.

What doesn't come through in your letter is that many of the source control improvements and associated environmental benefits were initiated by the Dairies of their own accord prior to signing the AOC, and others would have been implemented under updated regulatory requirements that apply in a balanced way to the dairy industry (such as the updated Confined Animal Feeding Operations or CAFO permit). Examples of early work performed by the Dairies prior to the AOC included construction and operation of the manure separation equipment, conversion of furrow irrigation systems in most of the fields to modern irrigation methods that are more protective of groundwater quality, and installation of backflow preventers in most of the water supply wells. The CAFO permit framework would have addressed, and does now address, nutrient application control, irrigation monitoring, and the assessment and upgrade of lagoon systems where appropriate.

While the Dairies are proud of the improvements they've made under the AOC, they continue to be very concerned that the same improvements could have and should have been achieved much more cost-effectively. The costs for making these additional source control actions have been born by the Dairies during an unprecedented downturn in the Dairy industry. The Dairies support investments in environmental protection, but the work needs to be performed in a streamlined manner so that the dollars spent produce effective outcomes without unnecessary waste and expense.

In short, they'd like to spend the money where it does the most good, and to do so in a manner more in line with the best practices within the Dairy industry.

We provided a number of recommended streamlining proposals for the AOC in September of 2017 and discussed those with your team in mid-2018. While a few of these changes have been adopted to date or even responded to, the Dairies would like to repeat their requests to EPA to consider these proposals in an effort to reduce unnecessary paperwork and optimize AOC implementation.

We also renew our request to approve the Dairies' prior reports that have been submitted for your review consistent with the AOC schedule requirements. There are more than a dozen of these reports awaiting final approvals.

3. Clarifications Regarding Your Comments and the Report Revisions

In considering your comments and the requested revisions, there are a number of important clarifications and comments that I felt needed to provide for the record, because some of the language in your letter can be seen as over-stating certain facts, or implying cause-and-effect relationships where causation has not been established. I've summarized ten of these instances below:

- **Misleading Description of Lagoons as "Gravel Lined":** In your general comments 3 and 4, your soil description language is speculative or is inconsistent with observed conditions. In specific comment 3 you state that Lagoon 14 "has a gravel bottom" and that Lagoons 4A and 4B "may have gravel bottoms". In general comment 4 you reference "nearby, upgradient gravel-lined lagoons" without specifying which lagoons you are referencing:
  - Soil testing has not yet been performed for Lagoon 14.
  - In our lagoon testing reports and other documents, we use applicable geologic terminology to describe soil conditions encountered.
  - The description of lagoons as being "gravel lined" or having "gravel bottoms" is misleading. It gives the reader the impression of a pure layer of coarse gravel as one might purchase from Home Depot to surround a French drain in a backyard. That type of a gravel layer has never been observed at the Dairies.
  - As you know, most of the soils present at Liberty and Bosma Dairies are mixtures of different levels of silt, sand, clay and gravel. The presence of some gravel in a mixture does not give the soil the hydraulic properties of pure gravel. The permeability of a soil is controlled by the overall soil composition, in particular the abundance of the finer soil fraction.
- **Removal of Language Regarding Fate of Nitrogen in Soil:** One of your comments (specific comment 6) asked for us to delete some language relating to the fate of nitrogen in soils. The original language simply outlined the four potential fates of nitrogen in the soil

profile. Those four potential fates are 1) uptake by the crop through capillary action, 2) held within the soil profile, 3) denitrified if wet conditions develop, or 4) move downward farther into the profile. You stated that the language should be deleted because "Soil conditions at the Dairies are generally not conducive to denitrification."

- Though we have deleted the language as requested, the basis for this request is not clear. Water-logged conditions do occur at times within the shallow soils at the Dairies, particularly after heavy rains or snowmelt. Though the overall quantity of water is limited (by the 7-inch precipitation rate typical of the Yakima Valley), denitrification can be triggered by such wet conditions in shallow, organic silty soils common at the Dairies.

- **EPA Request to Remove Groundwater Trend Information:** The Report previously included summaries of apparent groundwater trends, as analyzed using all data (5 years) and recent data (last 2 years). These trend analyses were meant to be informative and were performed using statistical methods commonly applied to groundwater (including the Mann-Kendall analysis and the Thiel-Sen trend analysis). In your comments (general comment 3 and specific comments 5a and 5d) you requested that all trend analyses be removed from the document, yet several of your comments and associated narrative (general comments 1 and 3, and specific comment 5b), continue to rely on trend conclusions.

    - In response to your comments we have removed the trend analyses from the document, however we did this with hesitation because the trend analysis information is informative and useful.
    - It is informative that of all 23 of the water table wells at the Dairies, 22 of them appeared to have either decreasing or stable trends as of year-end 2018.
    - The geographic pattern that we are seeing in wells where the trends have begun decreasing appears to tell an interesting story about how and where groundwater recovery is occurring.
    - Without presenting the trends or separating statistical noise from actual trends, the observations from the five years of completed groundwater monitoring remain largely inaccessible to most readers of the report.

We support an ongoing discussion of trend analysis methodology so that in the future we may provide a scientifically sound and reasonable presentation of groundwater trends for inclusion in the annual reports.

- **Nitrate Concentrations in Well DC-03 Relative to Other Benchmarks:** In your general comment 4, you characterize well DC-03 (without providing references) as having one of the most elevated nitrate levels in the United States, and you also state that it is not possible that such concentrations could be produced by discharges from septic systems. These statements are in conflict with readily available information in the scientific literature and the public record.
    - To say that well DC-03 is one of the highest nitrogen levels in the United States is simply not true. Much higher nitrogen levels have been measured in groundwater at other locations, especially at manufacturing and handling facilities for chemical fertilizers.
    - For an example of a higher nitrate concentration in groundwater, we have to only travel to downtown Sunnyside, Washington. At the Bee-Jay Scales site the operations of a chemical fertilizer handling facility resulted in groundwater nitrate levels up to 2,040 mg/L, nearly ten times higher than DC-03. Our staff have worked at other chemical fertilizer production or handling locations in the region with groundwater nitrate concentrations orders of magnitude higher than those observed at well DC-03.
    - With respect to septic discharges, you stated that typical nitrate (I believe this actually refers to total nitrogen) levels in septic system discharges are about 45 mg/L. However, this value is for well-designed and maintained septic systems functioning in appropriate geologic conditions. As the attached USGS study shows, much higher nitrogen levels can be observed. That study measured nitrogen levels in septic leach-field samples from four locations. The testing used soil lysimeters that directly measured the soil pore-water undergoing downward vadose zone transport. They encountered total nitrogen levels of up to 837 mg N/L in that downward-traveling pore water and encountered levels greater than 200 mg N/L at all four test locations.
    - The concentrations at DC-03 are significant, and source control measures have been and are being implemented by the Dairies to protect and restore groundwater quality. But there is no need for hyperbole regarding the nitrate levels in well DC-03.
    - For the time being, concentrations at well DC-03 have remained stable; neither increasing nor decreasing. This is likely to change in the future as groundwater restoration continues. Work conducted by the Dairies to protect and restore groundwater in the vicinity of DC-03 include the following:

- As we have discussed, Liberty and Bosma Dairies have been prioritizing source controls upgradient of wells YVD-14R and DC-03, working generally from upgradient to downgradient areas in a logical sequence. This has included irrigation system upgrades, field management upgrades, lagoon lining and abandonments, compost area improvements, manure handling area improvements and underground conveyance system inspections and repairs. Many of these improvements go well beyond the requirements of the AOC.

- Cow Palace has implemented, and is continuing to implement, source controls upgradient of well YVD-10 (that well is upgradient of well DC-03). These activities have similarly included irrigation system upgrades, field management upgrades, lagoon lining and abandonments, compost area improvements, manure handling area improvements and underground conveyance system inspections and repairs. Testing during the first two quarters of 2019 has shown apparent decreases in nitrate levels in well YVD-10. Such nitrate level reductions are expected to contribute to nitrate level reductions in downgradient groundwater areas over time (including wells YVD-14R and well DC-03).

- The time required to see a response in well DC-03 remains uncertain, because vadose zone transport timeframes throughout the Dairies have not been defined. Your dating studies from your 2013 report showed mean groundwater ages decades old, suggesting lengthy vadose zone transport timeframes. Saturated zone transport characteristics are better understood, but well-to-well transport times are on the order of multiple years, not months. Simply put, groundwater restoration follows behind source control implementation. This restoration lag has been noted over and over again in the scientific literature locally and globally. On this topic I recommend the 2018 review paper published by Sara Vero and others (Review: the environmental status and implications of the nitrate time lag in Europe and North America; *Hydrogeol J.* 26:7-22).

- **Uncertain Significance of Three Intermittent Ammonia Detections in Groundwater:** As noted in the original Report, ammonia was detected three times during 2018 (out of 75 discrete groundwater measurements during 2018). In your letter (General comment 4 and specific comment 5c) you concluded that these three detections demonstrate that these sporadic detections indicate that "these wells were impacted by nitrate sources that entered the ground recently and from locations that are close to the wells…" Given the sporadic nature and uncertain data quality for these low-level detections, it is not appropriate to jump to the conclusion that there is an uncontrolled source control issue near these three locations:

- The concern about data quality limitations for these three low-level detections is emphasized when you look closely at the data for each well. For example, in well DC-05, the sole ammonia detection during 2018 was present in the parent sample, but not in the associated field duplicate collected from the same well at the same time. Nor was ammonia detected in the paired total Kjeldahl nitrogen (TKN) analysis (TKN analysis also measures the presence of ammonia, in addition to any organic nitrogen). Ammonia was not detected during three previous years of monitoring in the same well, nor in the subsequent 6 quarters (including the first two quarters of 2019).

- Similar inconsistencies were observed in the other two wells where the ammonia detections were noted.

- We have also seen blank contamination for this parameter with this lab during previous sampling events (as described in our data validation reports, and in the Report). This type of false-positive is particularly common near the method reporting limits. We are stepping up our use of field blanks and are reviewing the laboratory's recent detection limit studies for ammonia to get a tighter understanding of the data quality limitations for this parameter.

- **Extent of Dairy Knowledge of Area Groundwater Quality:** The manure management provisions in Section 7 of the SOW state that the Dairies are to "...endeavor to avoid transporting manure to locations where groundwater is known by Respondents to currently exceed 10 mg/L nitrate. Applications of manure on crop fields in such areas is allowed only if post-harvest soil sample is 45 NO3-N or lower at the 2-foot depth." In your comments (general comment 5, and specific comments 2a, 8 and 9) you state that this scope of this knowledge extends "areas upgradient of, within the boundaries of, and within two miles downgradient of, the Dairy Facilities." In your comments you also state that the presence of a reverse osmosis system in a residence (even if groundwater data were not available) represents knowledge by the Dairies that groundwater in that location exceeds the nitrate MCL. The Dairies disagree with both of these statements.

    - The Dairies operate perhaps the most extensive groundwater monitoring networks of any operating dairy in Washington. Groundwater data collected by the Dairies includes ongoing monitoring at the 26 AOC wells, sampling (in 2013) at 75 off-site residential wells and ongoing monitoring an additional off-site groundwater wells installed under agreements with other parties. However, as shown in Figure 2 of the revised annual report the knowledge generated from these activities is limited to areas within and about 1 mile downgradient from the Dairies. The extent of this knowledge is consistent with the map contained in Appendix B, Figure 1 of the SOW. Counsel for the Dairies previously expressed to counsel for EPA (see joint letter addressed to Jennifer MacDonald dated February 1, 2017) their lack of concurrence with any more expansive view of the manure management provisions of Section III.F.7 of the SOW, especially given that AOC Section 48 prohibits the incorporation of other "agreements and understandings" into the AOC.

- For residences that already had an RO system, but chemical testing was not available or conducted, the Dairies have no knowledge about groundwater quality at that location except based on extrapolation from other nearby wells. The mere presence of an RO system does not in itself document the quality of the associated groundwater. This same situation applies to my Tacoma office, It has an RO system installed on our drinking water service. That unit was installed because some of my staff just "feel better" drinking RO-treated water. But we have never tested our drinking water for chemical contamination, and we have no reason to believe it is contaminated.

- In responding to your comments regarding off-site manure transfers, we have utilized the knowledge of groundwater quality as available to the Dairies. This results in some differences in conclusions regarding how these off-site transfers stack up against AOC expectations contained in Section III.F.7 of the SOW (see below for detailed discussion).

- **Implications of Irrigation Sensor Data Readings:** The Dairies currently operate a network of 83 irrigation sensors, with multiple sensors in each field. As we have noted in our proposals for AOC streamlining, this sensor network is well beyond industry norms and is very costly to operate. In your comments (General comment 4 and specific comment 7) you emphasized the need for optimizing irrigation controls, based on the presence of 69 soil moisture exceedances (exceedances of field capacity at the 3rd foot interval) detected during 2018. You referred to these exceedances as "significant." However, a closer look at the data shows that the performance record is in fact quite good.

  - Consistent with your comments (general comment 6 and specific comment 7) we have provided a more detailed summary of irrigation sensor operations for each field. That summary (Table 11 in the revised report) clarifies that during 2018 there were a total of 12,767 daily sensor readings throughout the 2018 irrigation season. Relative to that total, the 69 exceedances indicate that 99.5 percent of irrigation monitoring data indicated compliance with target moisture levels. Put another way, the exceedances represent a non-compliance record of .54% over the course of an entire year.

- The data also show that these limited instances of high moisture are limited in areal extent. Of the 34 application fields, none of the Dairy fields exhibited a moisture exceedance at more than one moisture sensor on a given day. That data pattern emphasizes the soil moisture exceedances, when observed, are not indicative of broad-scale over-irrigation, but are localized in occurrence.

- Finally, of the fifteen application fields exhibiting at least one exceedance of target soil moisture exceedances, only one of those fields (the one that you focused on in your letter) contained nitrogen levels exceeding the AOC target levels. This is important, because as field residual nitrogen levels are reduced, the significance of soil moisture exceedances is dramatically reduced.

- **EPA Recommendation for Additional Source Control Measures Near Well YVD-08:** In your letter (specific comment 5b) you recommended that significant new source control investigation effort be initiated within 30 days in the areas near well YVD-08, based on the apparent upward trend noted in nitrate levels in that well during 2018. In revising the Report, we have not incorporated those recommendations for the following reasons.

    - The measures recommended in your letter would constitute substantial additions to the existing SOW. As stated in the SOW, the annual report "...shall describe all activities undertaken pursuant to this Consent Order over the prior year." The Report is not the appropriate place to either impose or propose such a substantial revision and expansion to the SOW. Moreover, the AOC and SOW do not allow EPA to implement unilateral scope expansions of this type.

    - The comment letter implies that source control measures are not already in progress in this area. In fact, the following measures have been completed or pre-defined in EPA-approved documents:

        - Nitrogen levels in all application fields upgradient of well YVD-08 have been controlled to levels well below the target levels contained within the AOC and SOW.

        - Four of the five manure storage lagoons located in the vicinity of YVD-08 have already been lined.

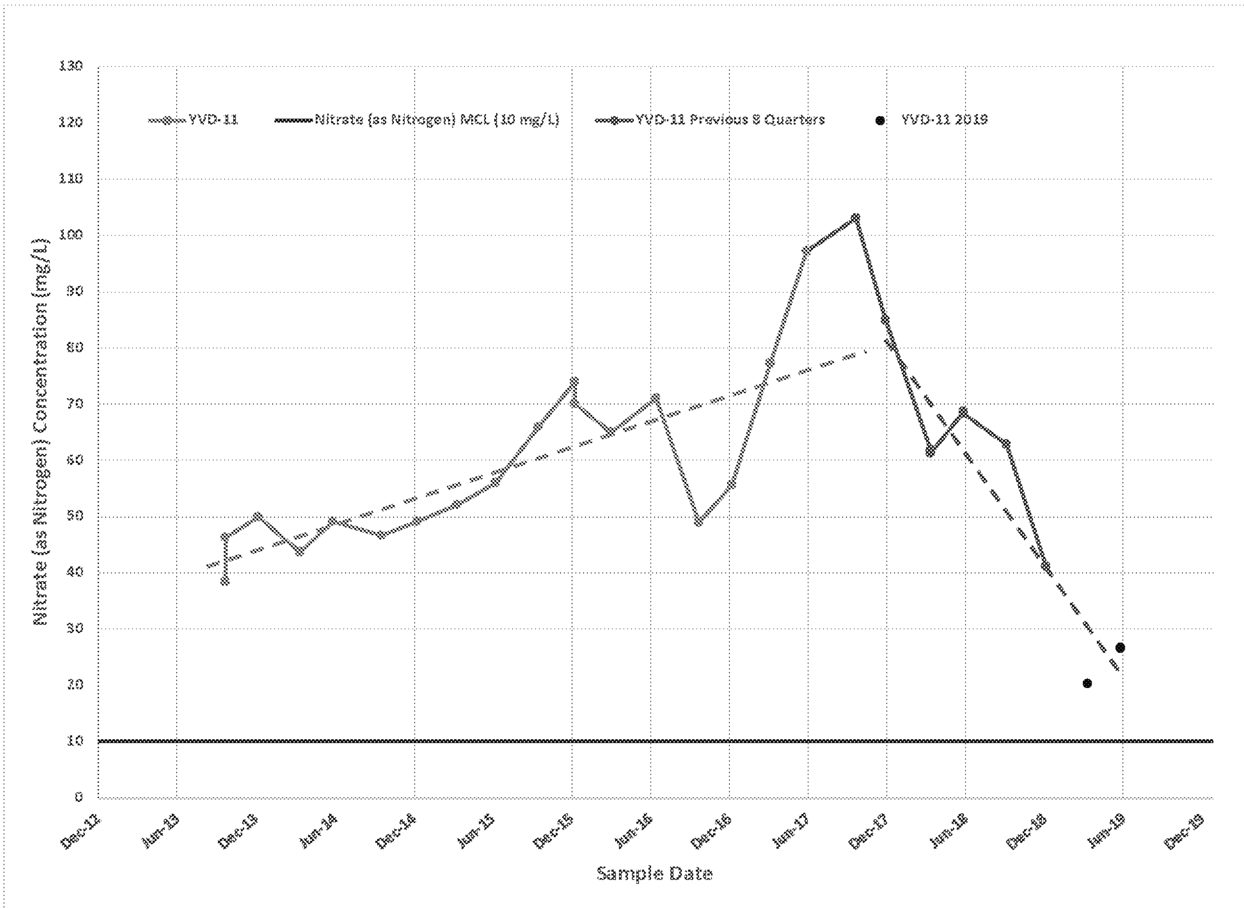
        - Soil testing conducted as part of well installation at YVD-08 and lagoon lining at Consolidated Lagoon 15 has documented the soil profiles immediately adjacent to the one remaining lagoon (Lagoon 14). That testing documented a low permeability layer (described as a sandy fat clay) located just below the bottom of Lagoon 15 (between 17.5 and 19.5 feet below ground surface. At boring YVD-08, the low permeability layer (described as a layer of clayey silt overlying a dry silt layer) was shown to be present between 16 and 35 feet below ground surface. The presence of this low permeability layer would be expected to lengthen groundwater lags associated with any source control activities completed in the vadose zone near the well. That is to say, the groundwater patterns and trends observed near YVD-08 are likely indicative of many years in the past, not what is currently happening on the ground surface.

- Additional data will be collected during pre-design investigation testing for the remaining lagoon (Lagoon 14). Predesign testing requirements have already been defined in an EPA-approved QAPP which will be implemented at the time Lagoon 14 is lined. That will most likely be 2020 or 2021. There is no need to revisit those testing procedures.

- The use of test pits to investigate piping integrity as proposed in your comment is not appropriate. Underground conveyance inspections addressing all piping (both pressure and non-pressure piping) were already completed by the Liberty/Bosma Dairies and the Cow Palace Dairy. There is no basis to initiate a new piping inspection at Liberty/Bosma Dairies.

- As communicated in our groundwater monitoring reports, trends in well YVD-08 may have begun to stabilize and reverse during early 2019. Specifically, the first-quarter and second-quarter groundwater monitoring reports for 2019 show that the concentration increases noted previously in well YVD-08 abated during this time, and nitrate levels decreased approximately 20 percent since year-end 2018. More groundwater nitrate monitoring is planned at this well consistent with the existing SOW. The results of that monitoring will confirm whether or not this apparent trend reversal is statistically significant and whether it will continue. We have seen other such trend reversals for central wells within the Dairies (e.g., reversal at well YVD-11 as shown in Figure below).

Figure 1. Apparent Reversal of Nitrate Trends at Well YVD-11



- **Discussion of Trends in DeRuyter Fields GDS-SU-06, -07 and -08:** A number of your comments (general comments 2 and 6, and specific comments 2b and 10a) relate to three application fields at D&A Dairy that failed to meet the nitrate performance standard during fall 2018. We have updated the application data and have updated the narrative in the Report to describe trends in each of these fields:
    - Nitrogen trends in field GDS-SU08 decreased year-to-year in both spring and fall 2018 (in comparison to 2017). These trends are appropriately described as decreasing in the 2018 annual report, though they have not yet met the AOC nitrogen target.
    - Trends in fields GDS-SU06 and GDS-SU07 did increase between spring 2018 and fall 2018. As discussed with you, the draft Report was in error. There were applications made in this time period to this combined field (the two fields are served by a single pivot) following the spring pre-plant sampling. Applications to field GDS-SU06 were slight less than, and the applications to field GDS-SU07 were slighty greater than the

recommendations provided by Agrimanagement. The applied nutrients were apparently not fully utilized by the crops prior to the fall 2018 sampling event. The report has been updated to document these applications and discuss observed trends in these fields.

- Nutrient budgeting, application controls and monitoring will continue in all three of these fields under the AOC and under corresponding CAFO permit requirements. No other corrective actions are warranted at this time, and none have been proposed in the updated Report.

- **Mis-Statements Regarding Off-Site Manure Transfers:** In several of your comments (general comment 5 and specific comments 2a, 8 and 9) you refer to off-site manure transfers as being conducted inappropriately to areas known by the Dairies to exceed a groundwater nitrate level of 10 mg/L and without appropriate soil testing. Specific comment 2a implies that inappropriate transfers were conducted at liquid manure transfer locations C2, D5, D6, D7 and D8 and at compost transfer location C1. This implication is repeated in specific comments 8 and 9. In five out of six instances, this implication is incorrect:

  - Liquid manure transfer location C2: Groundwater data available to the Dairies show that groundwater nitrate levels in the vicinity are less than 10 mg/L. This manure transfer was made after receiving soil testing data documenting that the owner's request for manure was made in compliance with agronomic rates.

  - Compost transfer location C1: This transfer was conducted to an area where available residential well sampling data indicates that groundwater nitrate levels do not exceed 10 mg/L. The presence of a previously-installed RO system near this location is not evidence of groundwater contamination in this area, as there are no sampling data indicating the presence of such contamination.

  - Liquid manure transfer locations D6 and D8: These two manure transfer locations were to areas where the closest groundwater data available to the Dairies did not exceed the nitrate MCL.

  - Liquid manure transfer location D7: Soil testing in the field to which this transfer was conducted demonstrated a soil nitrate level below 45 mg/kg in the second foot, in compliance with the requirements of the AOC.

  - Liquid manure transfer location D5: This one transfer was conducted in error by the contractor hired by the Dairy, as described in the draft Report. Corrective actions have been taken in response. These actions are described in greater detail in the revised version as submitted for your review.

Thank you for considering the information contained in this letter during your review of the revised Report and in our ongoing work on the project. We look forward continuing the good work at the Dairies, ideally with greater efficiencies.

Sincerely,

Mark Larsen
Partner and Principal Scientist

cc. Dan DeRuyter, GDS Dairy LLC and D&A Dairy LLC
Henry Bosma, Liberty Dairy LLC and H&S Bosma Dairy
Adam Dolsen, Jeff Boivin and Edward Miles, Cow Palace LLC
Lori Terry, Foster Pepper
Patrick Ryan, Perkins Coie
Brendan Monahan, Stokes Lawrence
Rene Fuentes, EPA Region X
Don Clabaugh, EPA Region X
Jennifer MacDonald, EPA Region X
Lucy Edmondson, EPA Region X
Ed Kowalski, EPA Region X
Chris Hladick, EPA Region X

Attachment: USGS Scientific Investigations Report 2006-5206

Prepared in cooperation with the Washoe County Department of Water Resources

Quantification of the Contribution of Nitrogen from Septic Tanks to Ground Water in Spanish Springs Valley, Nevada

By Michael R. Rosen, Christian Kropf (Washoe County Department of Water Resources), and Karen A. Thomas

Abstract

Analysis of total dissolved nitrogen concentrations from soil water samples collected within the soil zone under septic tank leach fields in Spanish Springs Valley, Nevada, shows a median concentration of approximately 44 milligrams per liter (mg/L) from more than 300 measurements taken from four septic tank systems. Using two simple mass balance calculations, the concentration of total dissolved nitrogen potentially reaching the ground-water table ranges from 25 to 29 mg/L. This indicates that approximately 29 to 32 metric tons of nitrogen enters the aquifer every year from natural recharge and from the 2,070 houses that use septic tanks in the densely populated portion of Spanish Springs Valley. Natural recharge contributes only 0.25 metric tons because the total dissolved nitrogen concentration of natural recharge was estimated to be low (0.8 mg/L). Although there are many uncertainties in this estimate, the sensitivity of these uncertainties to the calculated load is relatively small, indicating that these values likely are accurate to within an order of magnitude. The nitrogen load calculation will be used as an input function for a ground-water flow and transport model that will be used to test management options for controlling nitrogen contamination in the basin.

Introduction

The municipal water-supply wells in Spanish Springs Valley, Nevada (fig. 1), have shown increasing nitrate concentrations during the last 15 years. Seiler (1999) and Seiler and others (1999) concluded that nitrate increases resulted from an increased use of septic tank systems in the valley during this time. More than 2,000 septic tank systems were installed from the early 1970s to 1995. In 1995, the Nevada Division of Environmental Protection (NDEP) issued a ruling requiring Washoe County to ensure that all new housing development be connected to the municipal sewer system because of increasing nitrate concentrations in this sole-source aquifer. In April 2000, NDEP issued a directive to have all existing housing connected to the sewer system. Although the cause of increasing nitrate concentrations is relatively well known (Seiler, 2005), estimates of the amount of nitrate entering the aquifer and a nitrogen budget for the basin have not been developed. This study uses current data from soil water samples collected beneath septic tank leach fields to estimate the amount of nitrogen derived from septic tanks in the valley. This estimate will be used to develop a nitrogen budget for the basin, which then can be used by

Sample of soil water collected from Spanish Springs Valley lysimeter. Photograph by Michael R. Rosen.

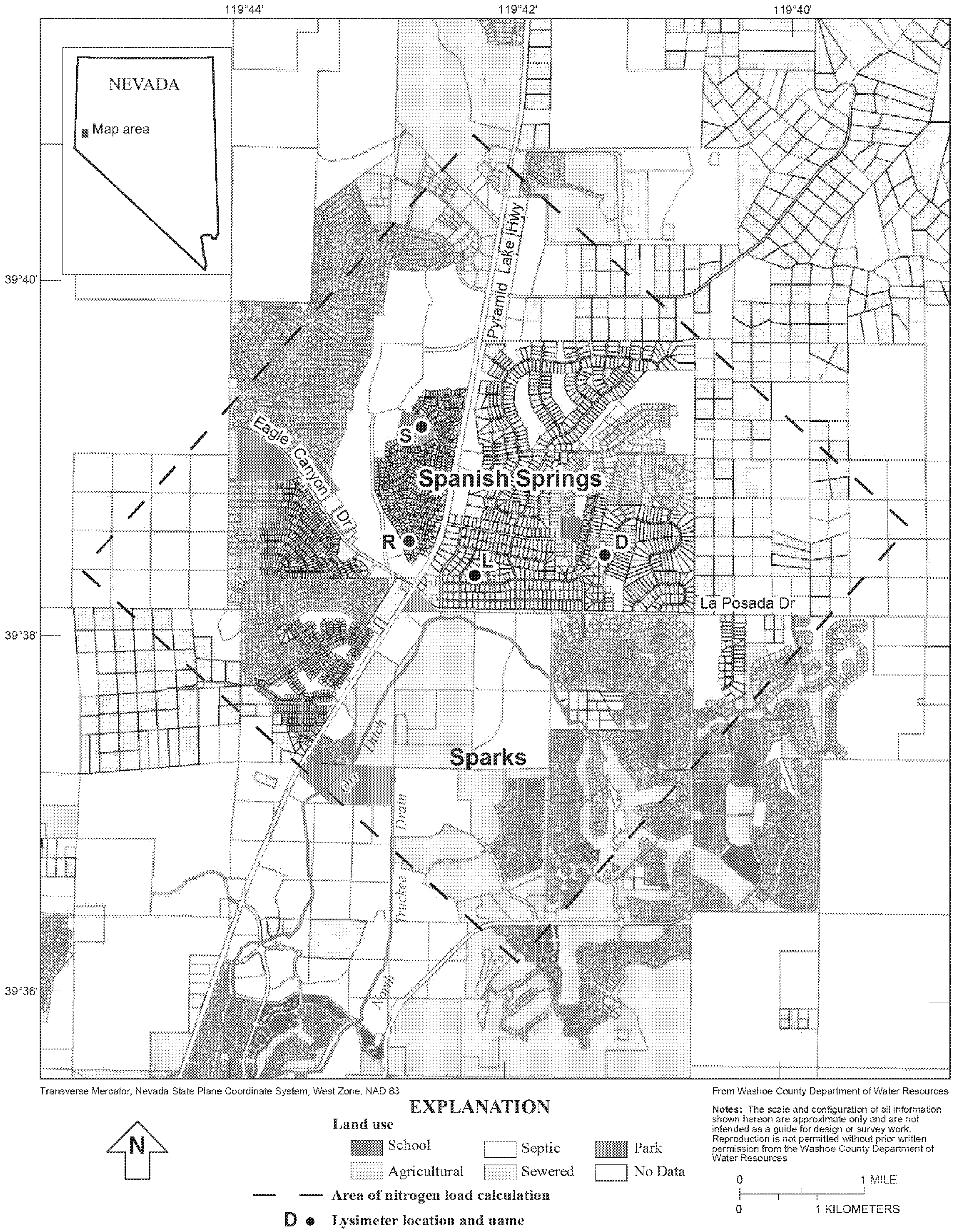
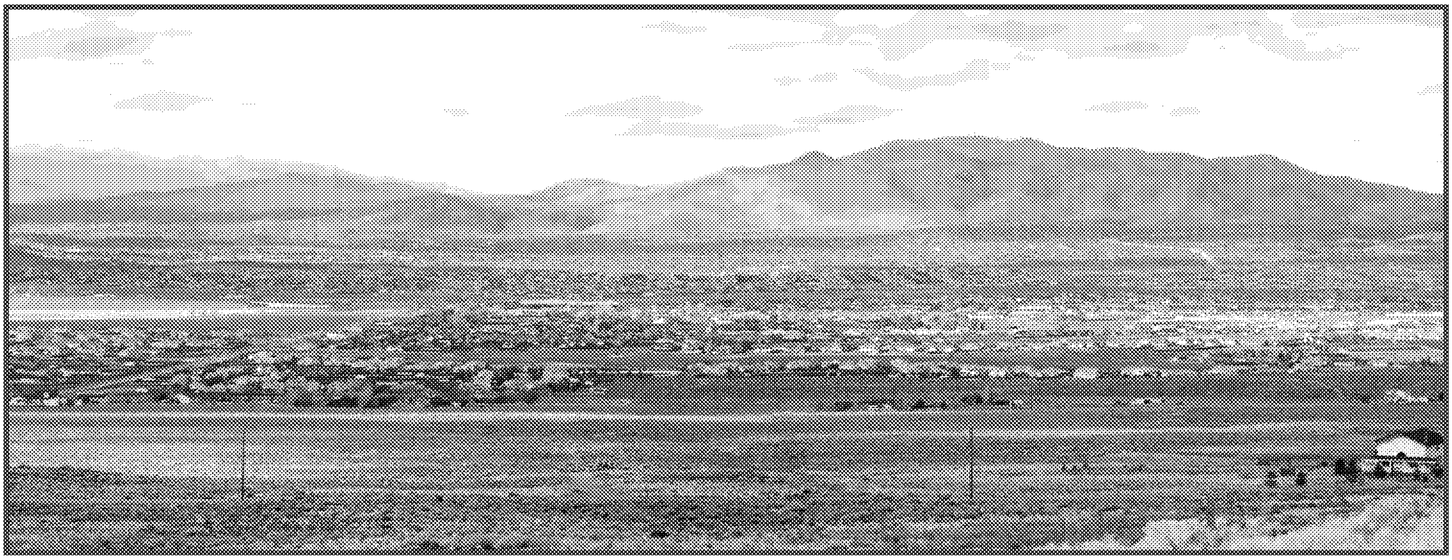


Figure 1. Location map of the Spanish Springs Valley study area. The dashed box, which is an area of approximately 34 km², used in the calculation of nitrogen loads. The letters R, L, S, and D are locations of the septic tank systems sampled.



Spanish Springs Valley looking west. Photograph by Michael R. Rosen.

managers to evaluate the effect of connecting all houses to the sewer system and the nitrate concentrations in the basin over time. Determining the amount of nitrogen originating from septic tanks will help Washoe County manage the existing water-quality problems with respect to nitrogen, plan the development of sewer systems that would maximize reductions of nitrate to the ground water, and provide information for different management scenarios that may include reuse of wastewater in the basin.

Description of the study area

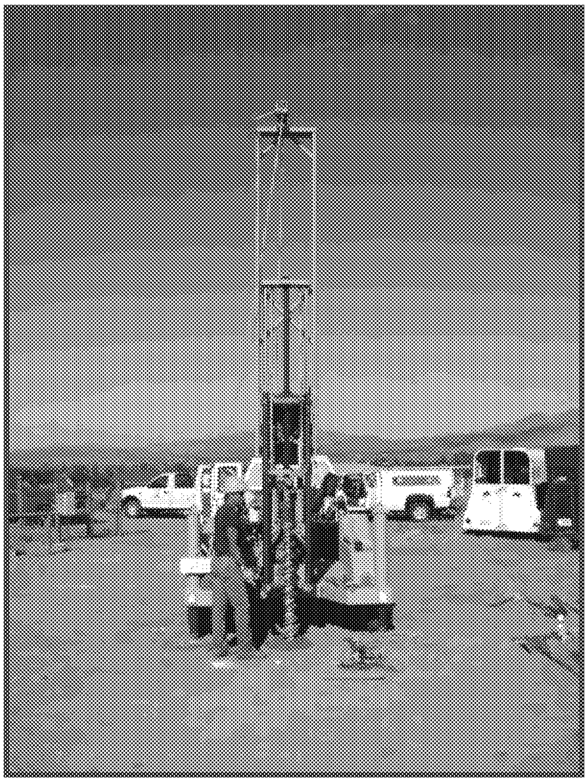
The study area encompasses the most densely populated area of Spanish Springs Valley, Nevada (fig. 1), a rural and suburban area north of Reno and Sparks, where septic tank systems have been used extensively since the 1970s. According to Washoe County parcel information, 2,070 septic tank systems currently are in the area within the dashed box in figure 1 [approximately 34 square kilometers (km^2)], and approximately 2,300 septic tank systems are in the entire basin. The valley is predominantly residential, with houses principally located on the valley floor and alluvial aprons in the central part of the valley. Alfalfa is grown in the southern part of Spanish Springs Valley in the area south of Orr Ditch. Sources of recharge in the study area are infiltration of precipitation, lawn percolation, septic tank system effluent, and infiltration of imported water used for irrigation (Berger and others, 1997). Annual precipitation on the valley floor generally is less than 20–25 centimeters (cm). Irrigation water is imported from the Truckee River to the Orr Ditch and into Spanish Springs Valley and is estimated to provide 54 percent of the annual recharge in the valley (Berger and others, 1997), and recharge from septic tank system effluent is estimated to provide about 17 percent of the annual recharge. Ground water discharges into the North Truckee Drain where it flows out to the south end of the valley. Ground water also discharges through evapotranspiration and subsurface outflow to the southern and possibly the northern parts of the valley (Berger and others, 1997). The basin-fill aquifer in the valley is primarily unconsolidated, interbedded deposits of gravel, sand, silt, and discontinuous lacustrine clay. These deposits are highly permeable and commonly transmit water rapidly (Berger and others, 1997).

Why was this study needed?

The recognition that high concentrations of nitrogen (more than 10 mg/L), specifically nitrate (NO_3^-), in drinking-water supplies could cause health problems was identified more than 50 years ago by Comly (1945). Methemoglobin, a form of hemoglobin that has been oxidized so that it is unable to carry oxygen, causes the disease called Methemoglobinemia. A bluish discoloration of the skin occurs when there are high amounts of methemoglobin in the blood. This condition, also known as blue baby syndrome, can be fatal. Infants under the age of 6 months are more susceptible to this disease because they lack the appropriate enzyme that reduces methemoglobin back to hemoglobin (Avery, 1999). Comly's research became widely accepted when subsequent research indicated a consistent pattern of high-nitrate drinking water in infantile methemoglobinemia cases. In 1975, the U.S. Environmental Protection Agency (USEPA) established a maximum contaminant level for nitrate in drinking water of 10 mg/L as nitrogen.

High nitrate concentrations also have been linked to hypertension (Malberg and others, 1978), central nervous system birth defects (Dorsch and others, 1984), certain cancers (Hill and others, 1973), non-Hodgkin's lymphoma (Ward and others, 1996; Weisenburger, 1991), and diabetes (Parslow and others, 1997). However, definitive relationships are lacking and more research is needed to confirm the links (Spalding and Exner, 1993). Avery (1999) suggested that the correlation between high nitrate concentrations and reported cases of methemoglobinemia may not be related to nitrate specifically, but to associated bacterial contamination that occurs with high nitrate concentrations in rural areas (for example, septic tanks and farm animal waste).

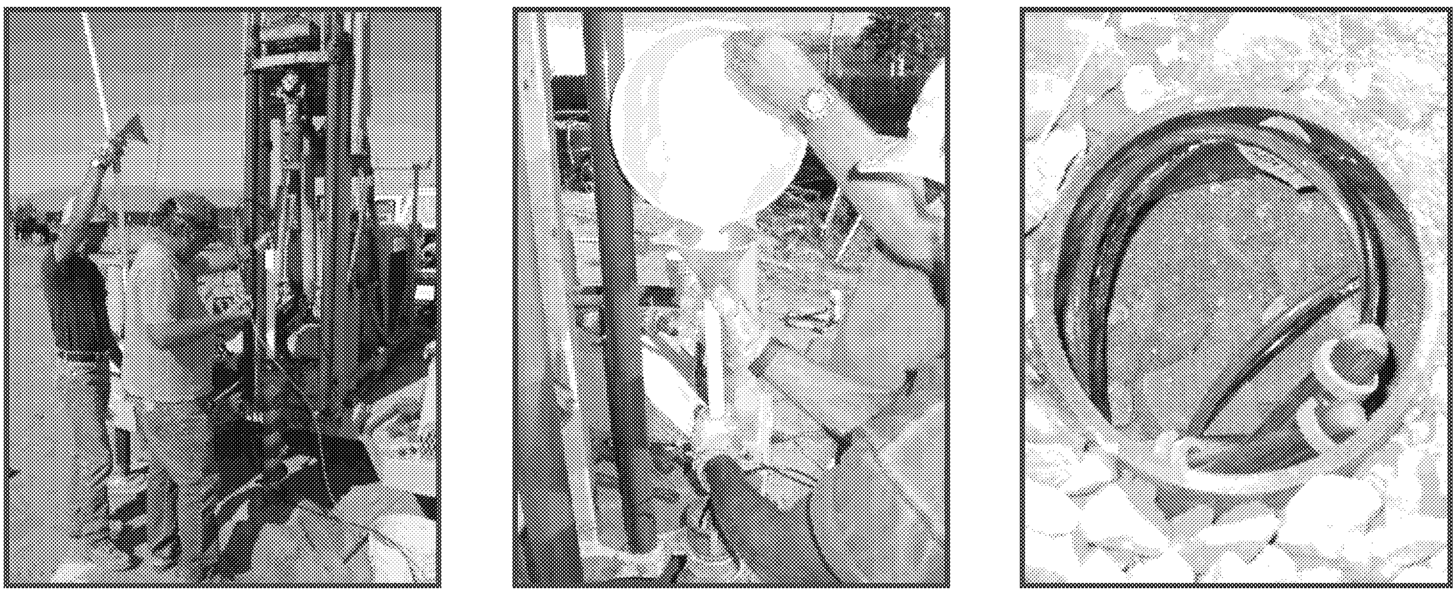
Nitrate concentrations approaching the USEPA maximum contaminant level in drinking water have been documented in water-supply wells in Spanish Springs during the past five years (Seiler, 2005). In addition, the water quality of other alluvial basins in Nevada also is being affected by increasing nitrate concentrations caused by septic tank systems (Seiler and others, 1999; Rosen, 2003; Shipley and Rosen, 2005). In order to address whether increasing trends in nitrate concentrations will continue, and how successful various management options may be in addressing nitrate issues in the basin, an accurate estimate of the amount (load) of nitrogen entering the ground water from septic tank systems is needed. The objectives of this study are to (1) determine the amount of nitrogen discharged from individual septic tanks by measuring the concentrations of the following nitrogen species: nitrate, nitrite, ammonia, and total dissolved nitrogen, that pass through the soil zone around septic tanks in Spanish Springs Valley; (2) determine if nitrate is lost in the soil zone by either chemical or biological reactions in the soil or both; and (3) estimate the total amount of nitrogen from Spanish Springs Valley septic tank systems that may enter the groundwater system.



Drilling to place lysimeters at Site D, Spanish Springs Valley. Photograph by Don Schaefer, USGS.

What Was Measured?

To estimate the amount of nitrogen originating from septic tank systems in Spanish Springs Valley, suction-cup lysimeters (Peters and Healy, 1988) were installed at four different septic tank locations labeled **R**, **L**, **S**, and **D** in figure 1. Suction cup lysimeters are porous ceramic cups that are placed in the soil at various depths using an augering device. The cup is sealed but has two plastic tubes at the top that reach the surface. The hole above the ceramic cup was sealed with bentonite and backfilled with native soil. Soil moisture from around the cup is drawn into the porous cup by applying

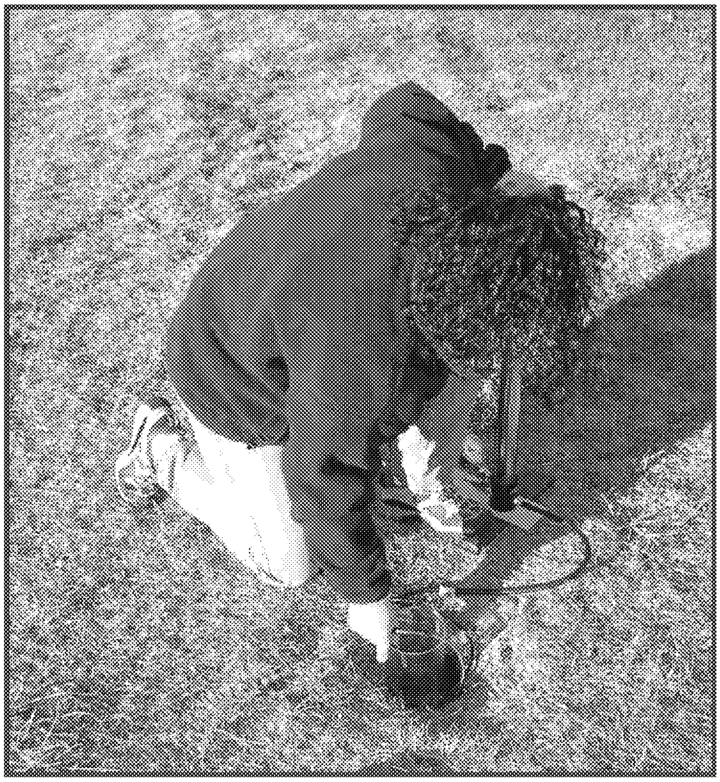


Placing a suction-cup lysimeter, sealing the hole with bentonite, and final hole showing sampling line after being backfilled with native soil. Left and center photographs by Christian Kropf; right photograph by Michael R. Rosen.

a vacuum on one tube using a handheld pump while the other tube is held closed. The vacuum is released the following day and the soil water sample is withdrawn from the ceramic cup by reversing the pressure on the vacuum tube and forcing the water up the opposite tube (sampling line) to the surface.

The four septic tank systems sampled for this study have been in use for various lengths of time and have different effluent volumes (because of the difference in the size of the systems). Three of the sites (**R**, **L**, and **D**) are septic tank systems for single family housing, and one site (**S**) is a septic tank system for a year-round elementary school. All of the leach fields have different configurations (fig. 2). The **R** site has a pipe that runs out of the septic tank to a "T" where the leach line is connected. At the **L** site, the leach line is laid out in two branches from the "T" pipe. At the **D** site, the leach line is connected straight from the septic tank, and at the **S** site, there are three branches to the leach line. The gravel packs around the leach lines are generally between 2–3 meters (m) deep because of low permeability soils on the valley floor. At each location, five paired lysimeters were installed, one at a shallow depth within the leach field gravel pack (less than one meter), and one below the gravel pack of the leach field (greater than two meters). All five pairs were installed below the leach line and within the leach field area of each septic tank. Two locations at site **R** did not have shallow lysimeters installed. A total of 38 lysimeters were installed within all the leach fields. One pair of deep and shallow lysimeters was installed outside of the septic leach field at each site as a reference site (**L1** in fig. 2). A total of 10 reference lysimeters were installed for this study. The nitrogen concentrations from the reference sites are not included in the calculations of the nitrogen load from septic tanks to the ground water. Nitrogen species and chloride concentrations were monitored monthly at each lysimeter from August 2004 to December 2005. Samples were not collected in January and February 2005 because heavy snow buried the lysimeters. A total of 424 samples were collected for this study: 331 samples (including 16 replicates) from the leach field lysimeters and 93 samples (including 5 replicates) from the reference lysimeters.

On the first day of sampling, a vacuum to 4.1 bar was created at each suction-cup lysimeter. However, some lysimeters did not hold a vacuum. On the second day, water was recovered from each lysimeter only if enough water had entered the lysimeter. The vacuum was never left on the lysimeters for more than 24 hours in order to minimize disturbance to the soil surrounding the lysimeter, which might create preferred pathways for contaminants (Peters and Healy, 1988). Water was not recovered from every lysimeter; water was recovered only periodically due to seasonal influences at some lysimeters. Water retrieved from the lysimeters was analyzed for total



Retrieving soil water sample from suction-cup lysimeter. Photograph by Anna Makowski, University of Nevada, Reno.

dissolved nitrogen, nitrate plus nitrite, nitrite, ammonia, and chloride. Organic nitrogen was determined as the difference between total dissolved nitrogen and the other nitrogen species measured. Due to limited quantities of water from some sites, analysis for nitrogen species was given the highest priority. If enough of the sample was available, chloride would be analyzed. For quality assurance, replicate samples were collected for five percent of the samples collected. Replicate concentrations of total dissolved nitrogen were all within 10 percent of the original sample and more than 50 percent were within five percent. Samples were filtered through a 0.45-micron filter to obtain only the dissolved fraction (although this fraction may include colloids or other fine particulates) and were collected and analyzed using standard U.S. Geological Survey (USGS) methods (U.S. Geological Survey, variously dated; Fishman, 1993; Patton and Kryskalla, 2003). All samples were analyzed at the USGS National Water Quality Laboratory in Lakewood, CO. All the data collected for this study are available from the National Water Information System web site (NWISweb; *http://waterdata.usgs.gov/nv/nwis/nwis*). Some lysimeters were dominated by high concentrations of ammonia, which is stable in low oxygen concentrations and some were dominated by nitrate, which is more stable in oxygenated conditions. Because of these different conditions, all diagrams in this report and all calculations of nitrogen loads were made on the total dissolved nitrogen concentrations, so that all lysimeters could be accounted for in the same way.

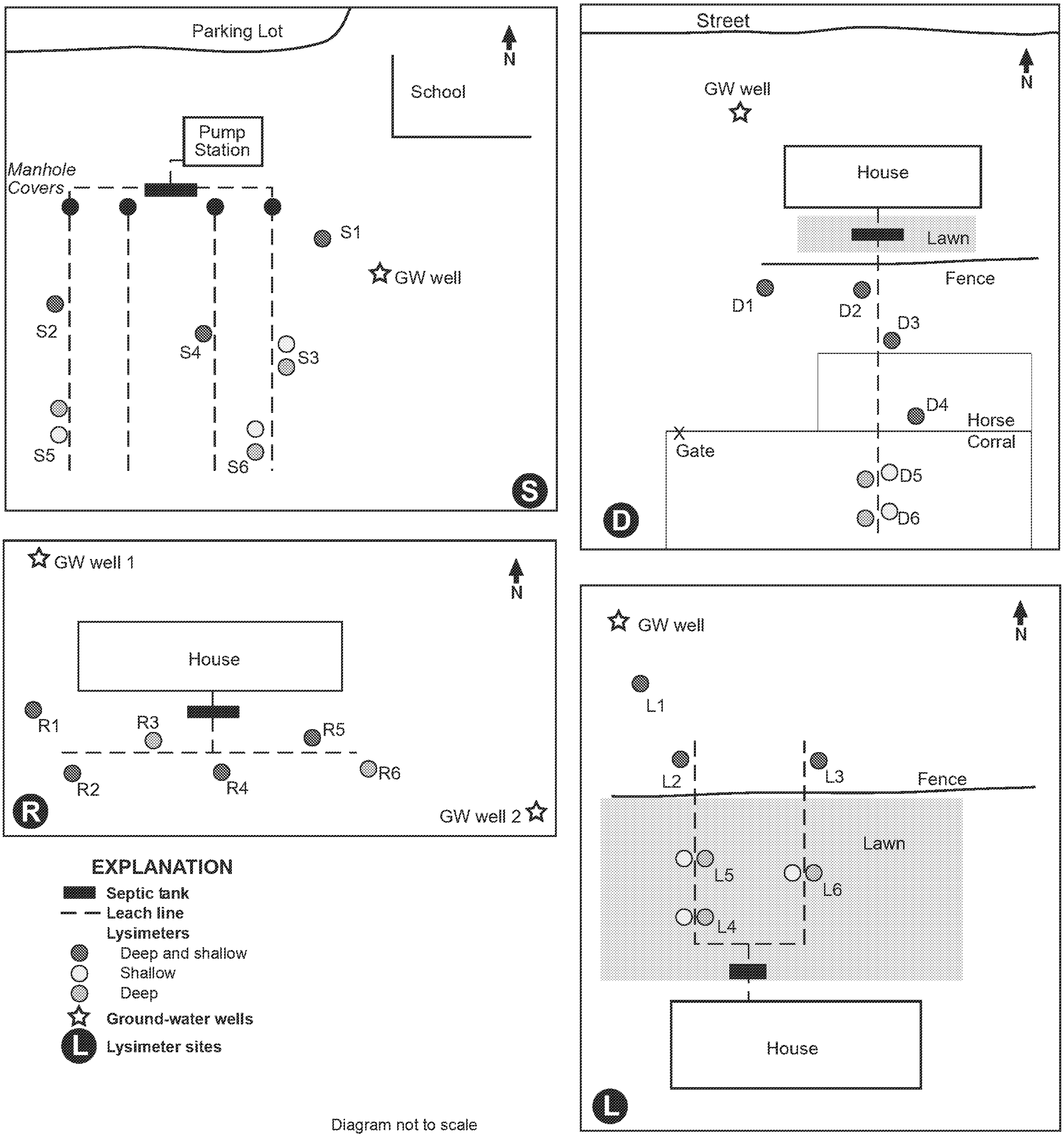


Figure 2. Location of lysimeters installed in the leach fields of the four locations used in this study. Except where lawn is indicated, the ground cover over the lysimeters is bare soil. See figure 1 for location of each system within Spanish Springs Valley.

The amount of dissolved nitrogen entering the ground-water system from these septic tanks was estimated using the data collected for this study. This value was used as a source term for septic tanks and extrapolated to estimate the total dissolved nitrogen, which is representative of nitrate loads from septic tanks for the area within the dashed box in figure 1.

How Were Nitrogen Loads Calculated?

Nitrogen loads were calculated using two different mass balance calculation methods developed by Bauman and Schafer (1985) and Hantzsche and Finnemore (1992). The difference between these two methods is that the Bauman and Schafer (1985) method includes input of ground-water flow and nitrogen concentrations upgradient from the areas of interest. It also includes mixing with water in the aquifer. The Hantzsche and Finnemore (1992) calculation only includes rainfall recharge as a water source directly on the area of interest. Therefore, the Bauman and Schafer (1985) nitrogen concentration calculations are lower (because of mixing with lower concentrations from lower in the aquifer and upgradient sources) than those calculated using the equation formulated by Hantzsche and Finnemore (1992). However, the change in mass of nitrogen added is small (less than 0.2 metric tons; 1 metric ton is equivalent to 1.1 U.S. tons) because the concentration of nitrogen in the water coming in from the aquifer (background nitrogen) is low.

The equation formulated by Hantzsche and Finnemore (1992) to determine the average concentration, n_r, of total dissolved nitrogen in recharge water to the aquifer is:

$$n_r = \frac{I * n_w(1-d) + R * n_b}{(I+R)} \qquad (1)$$

where

I is the volume rate of wastewater entering the soil averaged over the gross developed area;
n_w is the total dissolved nitrogen concentration of the septic tank water;
d is the fraction of nitrogen lost due to denitrification or ammonia volatilization;
R is the average recharge rate of rainfall in the area;
n_b is the background nitrogen concentration of rainfall recharge at the water table, exclusive of septic tank influences.

Values used for these parameters are listed in table 1. Most of the values for these parameters were taken from Berger and others (1997), Washoe County land parcel information, and unpublished soil core analyses. The total dissolved nitrogen concentrations for the septic tank systems (n_w) were derived from this study. In equation 1, n_w is the concentration of total dissolved nitrogen in the septic tank itself. In this study, the values for n_w are taken from the deepest lysimeters (below two meters depth). Because these concentrations represent nitrogen that has passed through the soil zone, it is assumed that any loss of nitrogen either through denitrification (nitrogen lost to the atmosphere as a gas by bacterial reduction of the nitrate in solution) or volatilization of ammonia (Heaton, 1986) has already occurred. Therefore, $d = 0$ for the calculations done for this study.

The Bauman and Schafer (1985) model treats the contribution of nitrogen from the septic tank systems in the same way as equation 1. However, Bauman and Schafer (1985) also consider ground-water flow from outside of the area (using Darcy's Law for ground-water flow) affected by septic tank effluent and also mixing of effluent with background aquifer water to a specified depth.

Table 1. Variables and values used for the Hantzsche and Finnemore (1992) model used to calculate loads.

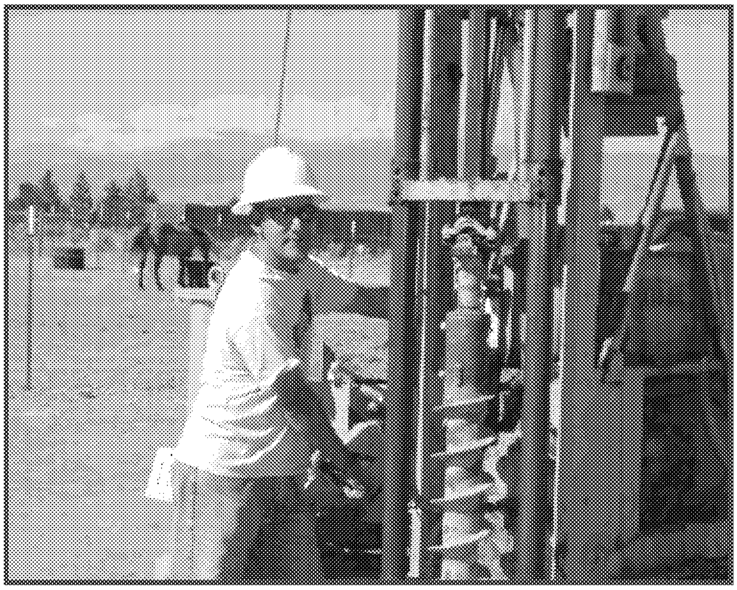
[Abbreviations: mg/L, milligrams per liter; mm/yr, millimeters per year]

Variable	Units	Description	Value used in calculations
n_r	mg/L	Resultant average concentration of nitrate-nitrogen in recharge water.	Result of calculation
I	mm/yr	Volume rate of wastewater entering the soil averaged over the gross development area	19
n_w	mg/L	Total dissolved nitrogen concentration of effluent from Spanish Springs Valley	44-50
d	percentage	Fraction of nitrate-nitrogen loss due to nitrogen losses in the soil	0[1]
R	mm/yr	Average recharge rate of rainfall	10
n_b	mg/L	Background nitrate-nitrogen concentration of rainfall recharge at the water table, exclusive of wastewater influences	0.8

[1]Nitrogen loss is assumed to be zero because the value for n_w is derived from measurements from below the root zone

In the Spanish Springs calculations it was determined that mixing occurred to at least 18.3 m based on nitrogen concentrations in ground-water samples. These other two background inputs tend to decrease the expected nitrogen concentrations to the aquifer because the natural concentration of nitrogen in the Spanish Springs aquifer was low (less than 2 mg/L). The system is assumed to be in a steady-state condition and although water and nitrogen leave the system through downgradient flow, the equations assume that no water or nitrogen is lost by pumping or consumptive use within the area of interest.

Calculations were made using both the Hantzsche and Finnemore (1992) and Bauman and Schafer (1985) models so that a range of estimated loads could be obtained. The median total dissolved nitrogen value rather than the average was used in the calculations because total dissolved nitrogen concentrations are highly variable and the use of an average value may be more influenced by outlier values than the median.



Drilling to place lysimeters at Site D, Spanish Springs Valley. Photograph by Don Schaefer, USGS.

How Did Nitrogen Concentrations Vary?

Total dissolved nitrogen concentrations ranged from less than 3 mg/L to greater than 800 mg/L at individual lysimeter sampling sites depending on the time of year and location. Table 2 lists the average and median concentrations of total dissolved nitrogen measured for each site, for all the deep and shallow lysimeters separately, and for all sites together. Most of the highest concentrations were from the shallow lysimeters, although concentrations greater than 300 mg/L also were recorded in some deep lysimeters. One lysimeter pair at site **D** that was located within a horse corral and had no lawn showed some total dissolved nitrogen concentrations greater than 800 mg/L, with a median value of 408 mg/L, but the deep lysimeter showed a median concentration of only 50 mg/L. The shallow lysimeter may be influenced by contributions of horses in the corral, whereas the deep lysimeter may better reflect the septic tank system input. Even without the influence of horses, total dissolved nitrogen concentrations varied by more than 100 mg/L at some shallow sites, although the deep sites were less variable (figures 3A-D).

Table 2. Average, range, and median total dissolved nitrogen concentrations (TN), one standard deviation (SD) of the average values, and sample counts for each sample site.

Site	Sample count	Average TN	SD	Median TN	Range
D shallow	28	296	232	213	18 - 837
D deep	72	43	50	30	2.8 - 311
R shallow	33	99	55	80	7.8 - 212
R deep	56	53	42	48	2.7 - 177
S shallow	24	94	99	57	1.8 - 344
S deep	22	70	64	58	4.2 - 255
L shallow	50	43	24	45	10 - 167
L deep	46	83	92	52	29 - 395
Shallow – all sites	135	120	150	64	1.8 - 837
Deep – all sites	196	57	61	44	2.7 - 395
All sites together	331	83	111	50	1.8 - 837

The average total dissolved nitrogen concentrations generally are higher than the median concentrations. However, large standard deviations of the data, particularly for the shallow lysimeters, reflect a high degree of month-to-month variability. This is expected due to seasonal and random differences in temperature, rainfall, irrigation on lawns, and changes in the number of people living in individual households. Extreme values tend to bias the data when averages are used, so to account for these extremes, the median values were used in all calculations. The median concentrations of the deep lysimeters are relatively similar between sites, ranging from 30 to 58 mg/L (table 2). No apparent correlation exists with location of the tank septic tank system within the valley, but the largest septic tank system (site **S**, at the year-round school) had the highest median total dissolved nitrogen concentration (greater than site **R** by 10 mg/L; table 2). The higher median total dissolved nitrogen concentration at the school may be because the primary use of septic tank system is the bathrooms. Little dilution of the high nitrogen concentrations occurs at the school from washing clothes and bathing, which would dilute nitrogen concentrations at most households.

At each site individually, monthly variations in total dissolved nitrogen concentrations could be highly variable, but when all the deep lysimeters are plotted together on a monthly basis, the median concentrations generally do not vary more than ±10 mg/L from the overall median

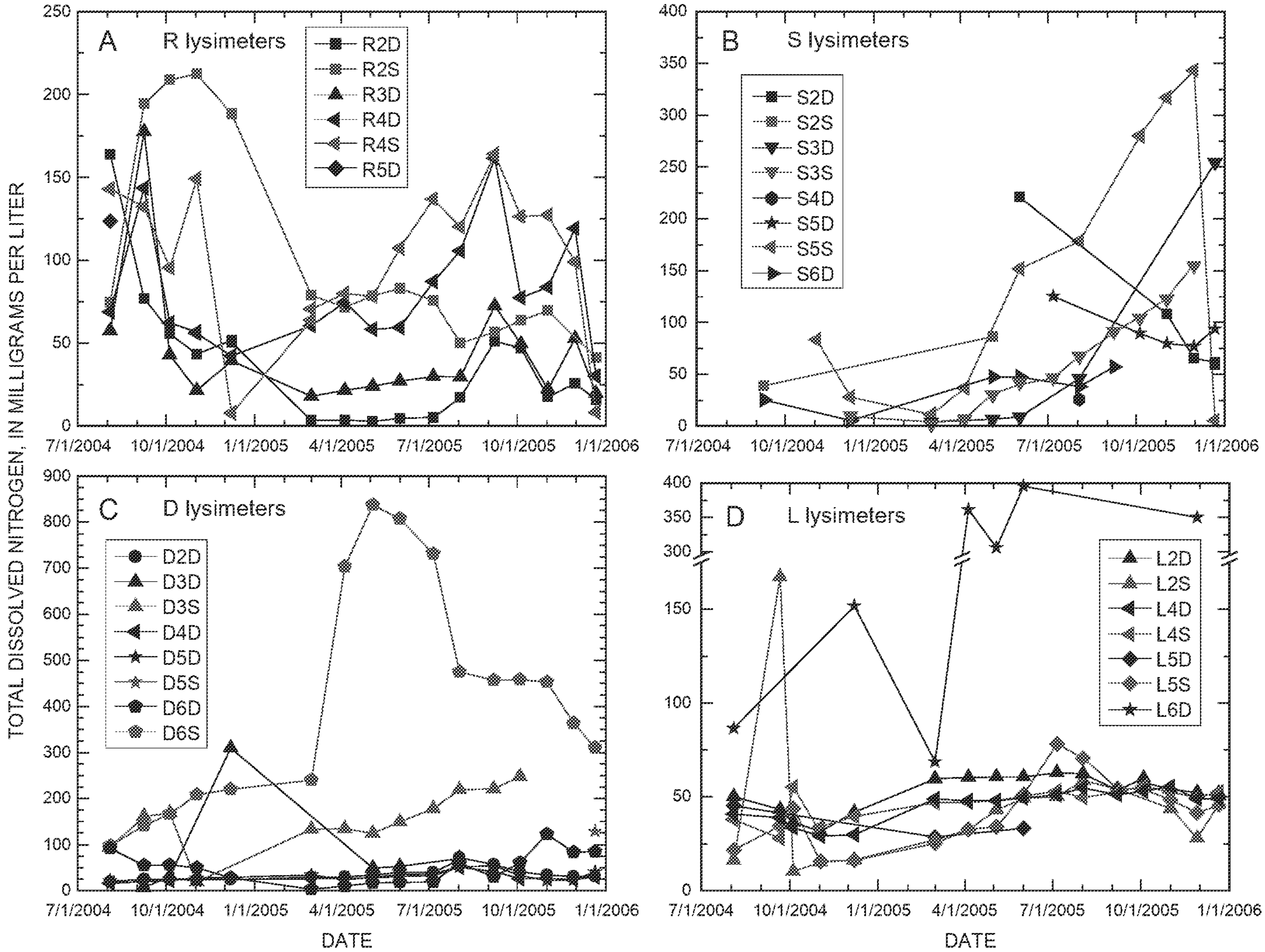


Figure 3. Monthly total dissolved nitrogen measurements from individual lysimeters installed in the four septic tank leach fields (*A*) R site (*B*) S site (*C*) D site (*D*) L site (note axis break on y-axis). Points and lines in red are shallow (S) lysimeters, those in black are deep (D) lysimeters.

concentration of 44 mg/L during the 18 months (fig. 4). This provides some confidence that the median total dissolved nitrogen concentration used in the load calculations is relatively consistent during this study.

Estimates of Nitrogen Loss

Nitrogen loss was estimated by using a literature value for the total dissolved nitrogen concentration from septic tank leachate before it enters the leach field and by comparing this value to the median total dissolved nitrogen value from the deep lysimeters. A value of 62 mg/L has been determined from analysis of more than 20 studies on septic tank systems throughout the country (Bauman and Schafer, 1985), but Hantzsche and Finnemore (1992) used more conservative values of between 40 and 50 mg/L. If the value of 62 mg/L is used, nitrogen loss of about 30 percent appears to be occurring before the leachate leaves the bottom of the gravel below the leach field. If the value of 50 mg/L is used, nitrogen loss is approximately 12 percent. Hantzsche and Finnemore (1992) estimate nitrogen loss to be approximately 25 percent, which is similar to the value obtained using a septic tank concentration of 62 mg/L. Bauman and Schafer (1985), however, assume no nitrogen loss occurs after nitrogen leaves the septic tank. Our calculations indicate that nitrogen loss between 12 and 25 percent is occurring in the Spanish Springs Valley leach fields; this number could be better refined if chemical and isotopic analyses were performed on the septic tank leachate.

How Much Nitrogen Is Contributed By Septic Tanks?

If the median concentration of all the deep lysimeters (44 mg/L in table 2) is used for n_w in equation 1, the concentration of nitrogen in recharge water in the study area is calculated to be 29 mg/L. If the Bauman and Schafer (1985) calculations are used and a mixing depth of 18.3 m is used, the nitrogen concentration is calculated to be 25 mg/L. The difference is caused by mixing with

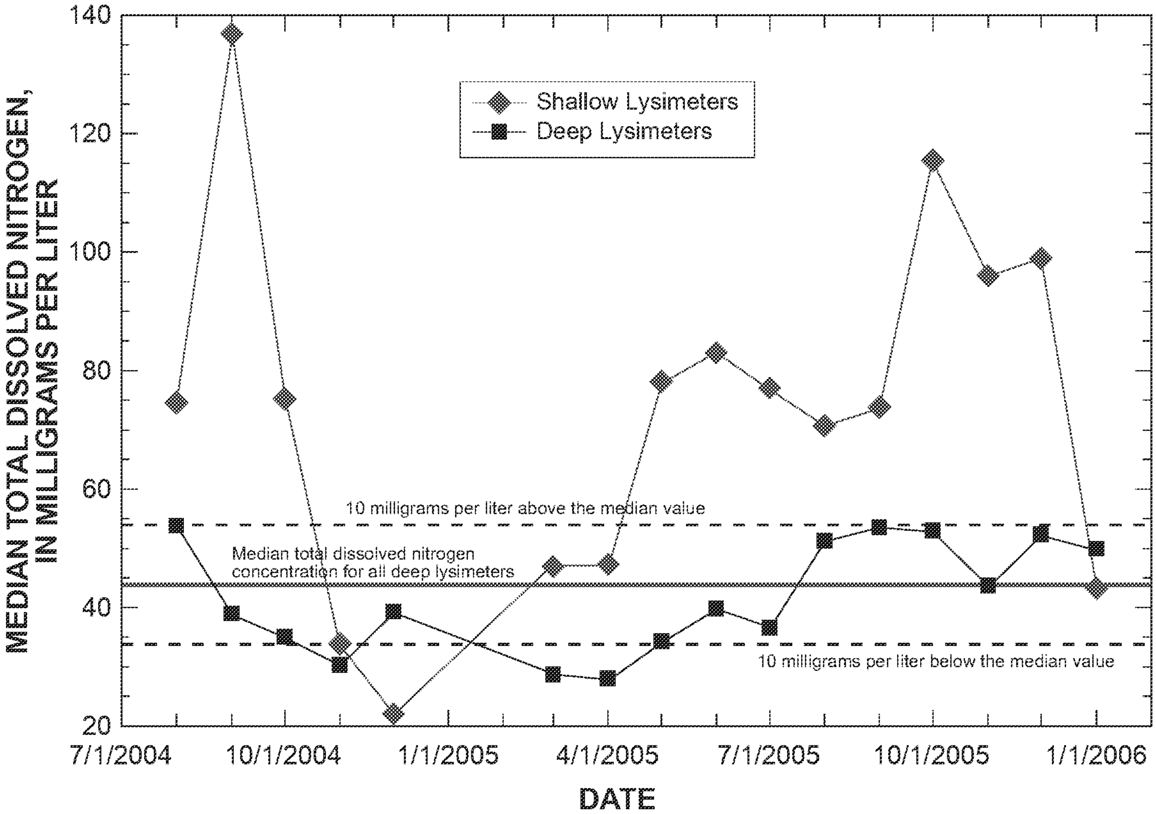


Figure 4. Median total dissolved nitrogen concentrations for all shallow and all deep lysimeters sampled within the leach fields of the septic tank systems. Calculations of nitrogen loads were made from the total dissolved nitrogen concentrations for all deep lysimeters.

upgradient water that contains low nitrogen concentrations (estimated as less than 2 mg/L for this study). The calculated recharge values (25–29 mg/L of total dissolved nitrogen) can be multiplied by the number of septic tanks in the study area (2,070) and the volume of water derived from septic tank systems to determine the load of nitrogen to the basin (both the natural and septic tank recharge load). For the Bauman and Schafer (1985) equation, the volume of water added from upgradient ground water also is included. However, because this water is low in nitrogen, it does not change the mass load by more than 0.2 metric tons. Estimates of the volume of water from septic tank systems in Spanish Springs Valley have been calculated by Washoe County Department of Water Resources by taking the average of household water usage during the winter when there is no irrigation. The value for daily septic tank water volume discharge is 860 liters per day (L/d) per household. The volume of water coming from natural recharge is approximately 460 L/d covering the area where the septic tank systems are operating. Therefore, the total volume of water entering the aquifer is approximately 1,320 L/d. By multiplying this volume by the number of septic tank systems and the concentration of dissolved nitrogen in the recharge, this equates to about 29 metric tons of nitrogen contributed to the aquifer by septic tank systems and natural recharge within the dashed box in figure 1 each year. If the median concentration for all lysimeters is used (50 mg/L in table 2) the amount of nitrogen contributed to the aquifer is approximately 32 metric tons of nitrogen per year. These estimates of total dissolved nitrogen contributions from septic tank systems are based on the median contribution from only four septic tank systems in Spanish Springs Valley. However, the size of the septic tank systems, number of people living in a household, and the location and age of the septic tank systems are typical of the area. Therefore, it is unlikely that these estimates will be grossly inaccurate. Natural recharge contributes only about 0.25 metric tons of nitrogen to the aquifer because the concentration of nitrogen in natural recharge is so small (0.8 mg/L) compared to the septic tank concentrations (44–50 mg/L). This indicates that virtually all of the nitrogen accounted for in the calculations is from septic tank systems in this part of the aquifer. Some contributions from lawn fertilizers and animals also may contribute additional nitrogen to the aquifer, but because the septic tank systems analyzed in this study were mostly in bare soil areas that did not have abundant lawn (except 3 lysimeters at site L) or animal impacts (except 3 lysimeters at site D). The load calculated here is almost exclusively caused by septic tank system inputs.

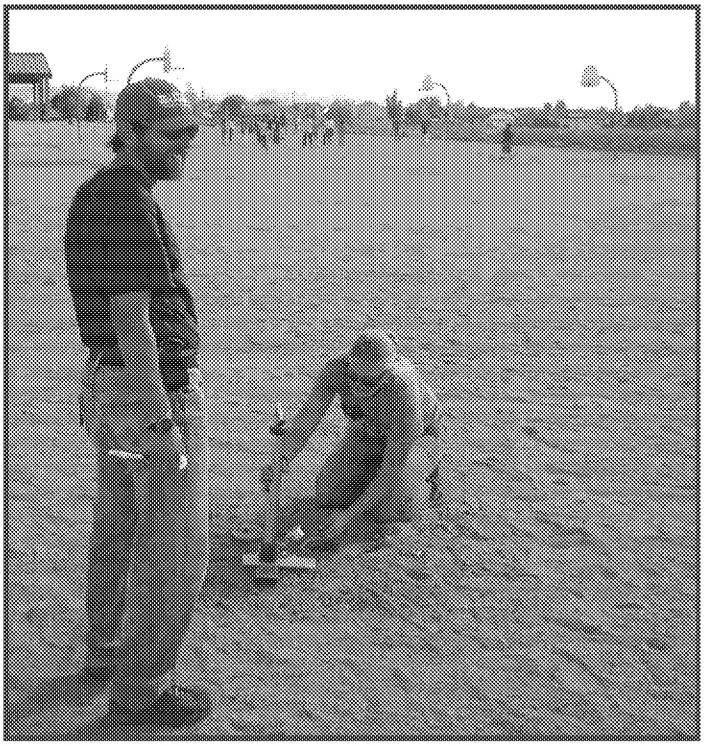
Sensitivity analysis of the Hantzsche and Finnemore (1992) equation shows that total dissolved nitrogen recharge from septic tank system inputs is the most important parameter to estimate accurately. Doubling or decreasing by half the infiltration rate of wastewater through the soil (I) only changes the nitrogen concentration in recharge water by approximately 6 mg/L (a difference of 4 metric tons of nitrogen). Changing the background nitrate concentration (n_b) will only raise the contribution from septic tank systems if the value is increased significantly (greater than 5 times the concentration used) and a high background total dissolved nitrogen concentration is not possible over the entire aquifer because measurements of deep wells show total dissolved nitrogen concentrations similar to the low background value (less than 2 mg/L) used in this report (Washoe County Department of Water Resources, written commun.). The estimates given here are likely to be accurate to within at least one order of magnitude and probably are better than that, based on the sensitivity analysis. Sensitivity analysis of the Bauman and Schafer (1985) mass balance calculation yields a similar result.

Conclusions

Based on over 300 measurements of total dissolved nitrogen concentrations in soil water below leach fields of 4 septic tank systems in Spanish Springs Valley, two mass balance calculations were made and show that approximately 29 to 32 metric tons of nitrogen are contributed to the shallow ground water from septic tank systems and natural recharge each year. Almost all of the nitrogen is contributed by septic tank systems as the natural recharge accounts for only 0.25 metric tons of nitrogen. The estimates have some error associated with them based on uncertainties in rainfall recharge, septic tank volumes discharged and ground-water flow rates, but even with these uncertainties, the estimates are within one order of magnitude of what is likely. Many of the parameters that are the most uncertain, such as rainfall and volume rate of wastewater entering the ground water, need to double in order to have a significant impact on the mass of nitrogen calculated.

What Future Work Is Needed?

Additional water-quality and ground-water flow data are being collected from monitoring wells and production wells to better understand the distribution and transport of nitrate in the aquifer system. Age dating of the ground water is needed to determine how quickly ground water and contaminants move through the aquifer. The results from this study combined with this additional data is planned to be used as input functions for a contaminant transport and flow model presently being developed by the Desert Research Institute. This model will be used to determine the best management scenarios for controlling and mitigating nitrogen contamination within Spanish Springs Valley.



Obtaining a water sample from the lysimeter at site S. Photograph by Christian Kropf.

Acknowledgments

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Spanish Springs Valley looking west. Photograph by Christian Kropf.